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The contribution of renewable distributed generation in mitigating carbon dioxide emissions

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ABSTRACT

The traditional approach in electric power generation is to have centralized plants distributing electricity through an extensive transmission and distribution network. Distributed generation (DG) provides electric power at a site closer to the customer, eliminating the unnecessary transmission and distribution costs. In addition, it can reduce fossil fuel emissions, defer capital cost, reduce maintenance investments and improve the distribution feeder voltage conditions. This study calculates and compares the cost of line losses, cost of transmission and distribution in the case of laying additional transmission line, the cost of carbon dioxide (GHG) emission in the case of fossil-fuel based distributed generation, and the cost of using renewable distributed generation in providing additional supply of power to a small rural electric utility. Results show that optimally located DG which is renewable in nature is economical in the long run when factors of fuel costs and carbon dioxide emissions are taken into account. The PV plant is the most economical because it can be moved to optimal location, followed by the wind and hydro, which are geographically fixed.

Contents

1. Introduction

The situation in most small, island based electric utility is that they are supplied electric power from the mainland through submarine cables. Although submarine cables are very robust, are designed and known to endure beyond their life-span, they are also expensive, are subject to weather and undersea disturbance and may still require difficult and expensive repairs to be made. Furthermore, due to the power crisis in Mindanao the cost of energy and its availability have become a prime concern both of the utility administrators and the consumers as well. The aim of this study is to provide a cost analysis between laying a new submarine cable, or putting up fossil-fuel based DG, or renewable DG, on an island based electric cooperative to meet the need for power in the next twenty five years. Although this study mainly compares the economic benefits of each option, its focus however, is on the cost of carbon emission or reduction and its computational algorithm.

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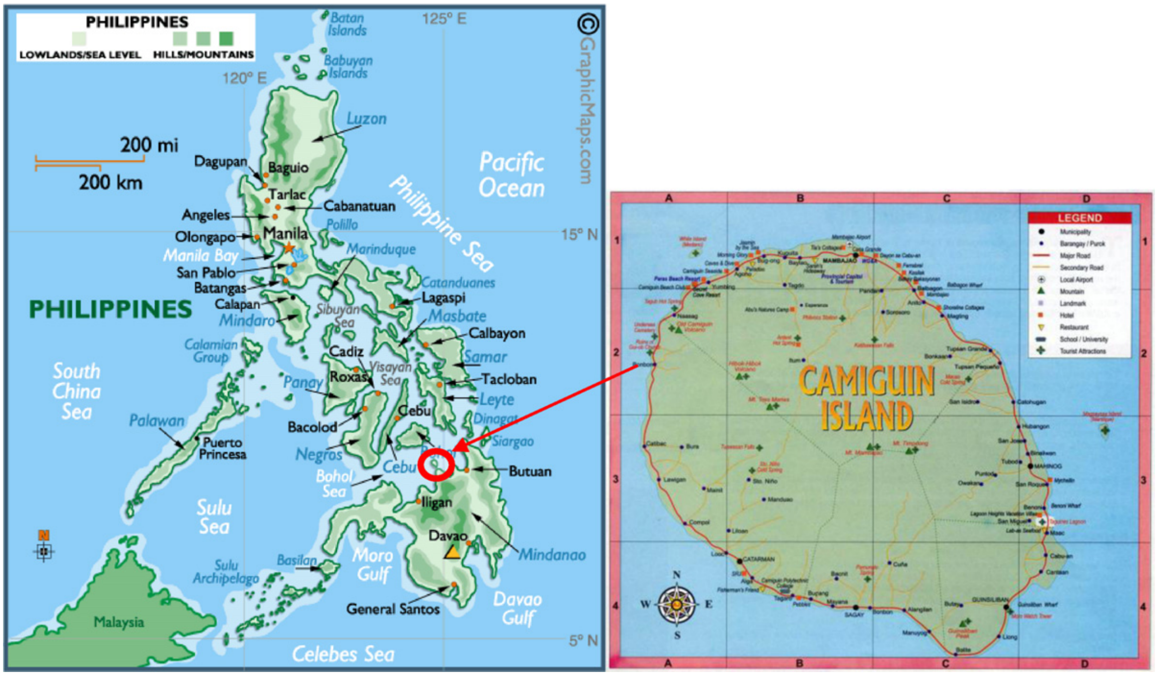


Fig. 1. Philippine and Camiguin island maps.

Camiguin is an island province of the Philippines located in the Bohol Sea, about 10 km off the northern coast of Misamis Oriental in Mindanao. It is the second-smallest province both in population and land area next only to Batanes. The capital of the province is Mambajao and it is a part of the Northern Mindanao region.

Camiguin is about 300 km^2 and approximately 29,000 ha; its length measures 33 km, widest point is 14 km with road circumferential measuring to 64.58 km. The panorama of the island is a scenic variety of mountains, shorelines and coral reefs. Three of its highest peaks are Mount Timpoong (1580 m), Mount Mambajao (1400 m) and Mount Hibok-Hibok (1250 m). Camiguin has five municipalities or towns (Fig. 1).

The electricity of the island is supplied through a submarine cable going to the receiving point at Liong Switchyard, Liong, Guinsiliban and power is distributed to two feeders (Fig. 2).

2. Methodology

In this study, historical data of monthly power demand and energy were gathered from the last eight years and forecasted for the next 20 years. This is done in order to determine what will be the size of cable to replace the old one or what will be the size of the DG units to be installed. (Fig. 3), and graphs are provided below to give a concrete view. This work then proceeds to provide and compare three options to meet this requirement.

The comparison is firstly on the technical loss based on computer simulation of the system, secondly, on environmental effects of carbon dioxide emissions, and thirdly on the economic benefits. The first option is to lay a submarine cable, the second option is to put up a small coal or diesel (light-fuel-oil or LFO) generation unit, and the third option is to put up renewable energy generation units. Furthermore, three options of renewable energy units are compared: photovoltaic (PV), small hydro, and wind turbines. All values for generation, transmission and distribution costs are taken from present prevailing rates and the cost of money are assumed to be 10%.

Fig. 3 shows the annual peak demand from year 2001 to 2028, which occurs only on December each year. As early as 2009 the peak load already exceeded the 80% (of 5 MW) tolerable load limit which is 4 kW. This is detrimental to the life-span of the submarine cable which is almost over already. The peak load for year 2028 is 6.460 MW. Fig. 4 shows the corresponding energy sales forecast from 2009 to 2028 [1].

According to the Grid Code requirement, submarine cable should be rated 1.43 (it should be loaded up to 70% of its rated capacity) times its load requirement. To bear a load of 6.460 MW, a 10 MW submarine cable is needed. Economic calculation shows that a 13.2 kV rated is beneficial over a 34.5 kV rated cable.

The Grid Code also specifies that generators (coal, bunker or diesel fueled) should be rated 1.25 times its maximum load. So, the DG unit for coal and diesel should be 1.25 $\times$ 6.460 MW or 8 MW. For a more reliable operation, 10 MW DG would be more advisable. A 10 MW coal-fired generator system is also considered [1–5].

2.1. Comparison of technical loss

Renewable DG systems inherently provide some benefits to the utility. They may level the load curve, improve the voltage profile across the feeder, may reduce the loading level of branches and substation transformers, and provide environmental benefits by offsetting the pollutant emissions. Utility economic benefits also include loss reduction, avoided costs of energy production, generation capacity, distribution and transmission capacity investment deferral, reducing risk from uncertain fuel prices, green pricing benefits, etc [6].

Further, the impacts of dispersed generation at the distribution level are performed with an emphasis on resistive losses, and capacity savings. The results show the importance of placement for minimizing losses and maximizing capacity savings [3].

Fig. 5 is a graphical presentation of the simulation result on the system to determine its line losses of the different schemes of

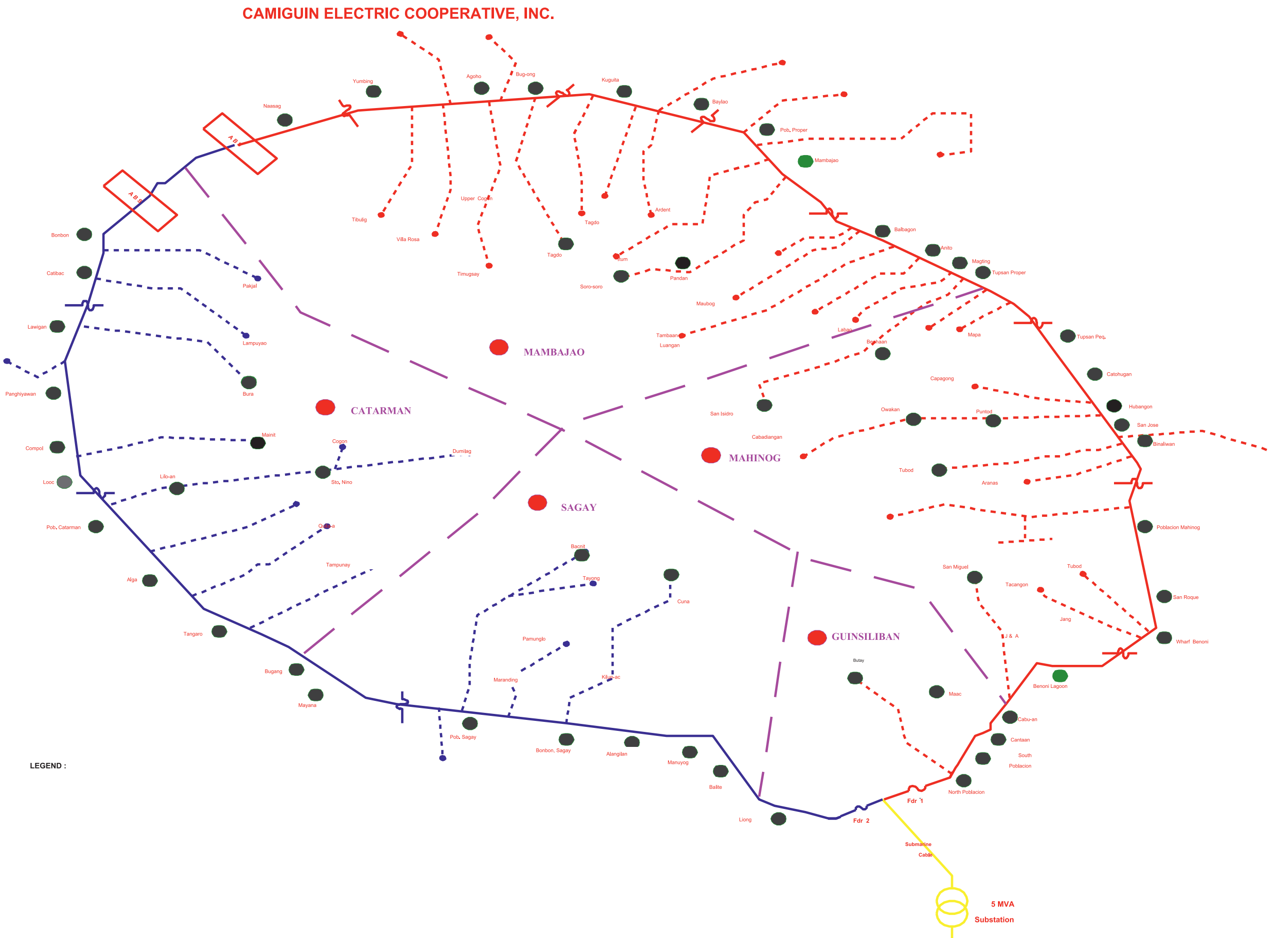


Fig. 2. Topographical one-line diagram of Camiguin distribution system.

generation. From this data, it could be seen that PV, diesel, and coal have the least technical losses, then they are followed by the submarine cable. Wind and hydro have the greater losses. All these are due to their location in the system. PV, diesel and coal could be optimally placed through simulation studies, but the location of wind and hydro generation system are fixed by the availability of the resources. A change in the distribution circuit topology may help to alleviate this situation. Although in this study the focus is on mitigating carbon dioxide emissions by using renewable DG, this section on technical loss is considered because renewable DG are location limited, and this may cause large line losses as in this case. But solutions maybe found if the power generated would be enough to account for the losses.

2.2. Comparison of green house gas emissions

Fig. 6 shows the algorithm used for determining the CO_2 emissions of fossil fuel based generating plants. Figs. 7–10 show the

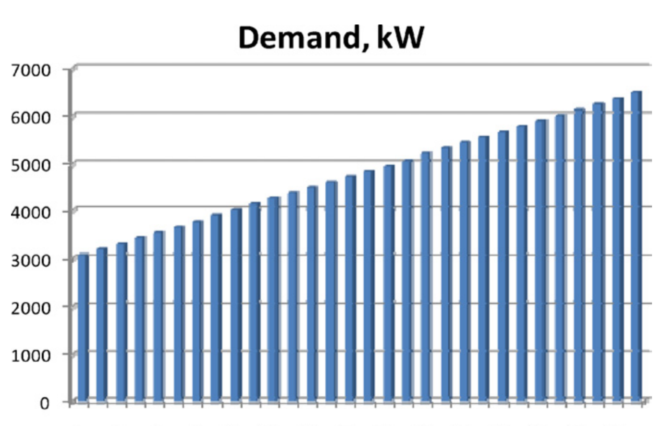


Fig. 3. Annual peak load from 2001 to 2030 in MW/year.

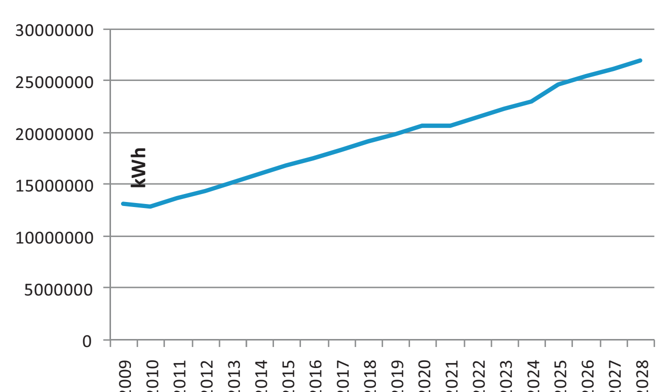


Fig. 4. Energy sales in kW h per year.

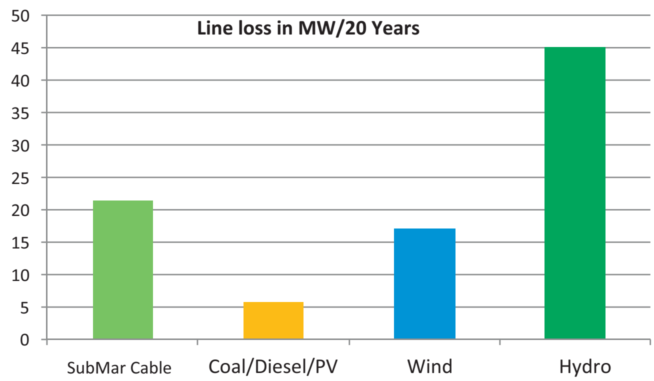


Fig. 5. Comparison of technical loss.

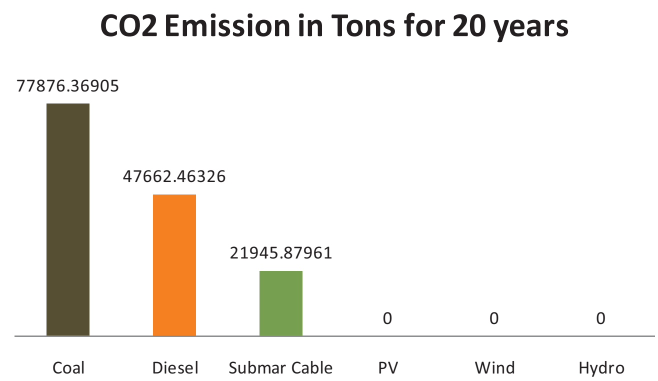


Fig. 7. Comparison of carbon dioxide emissions.

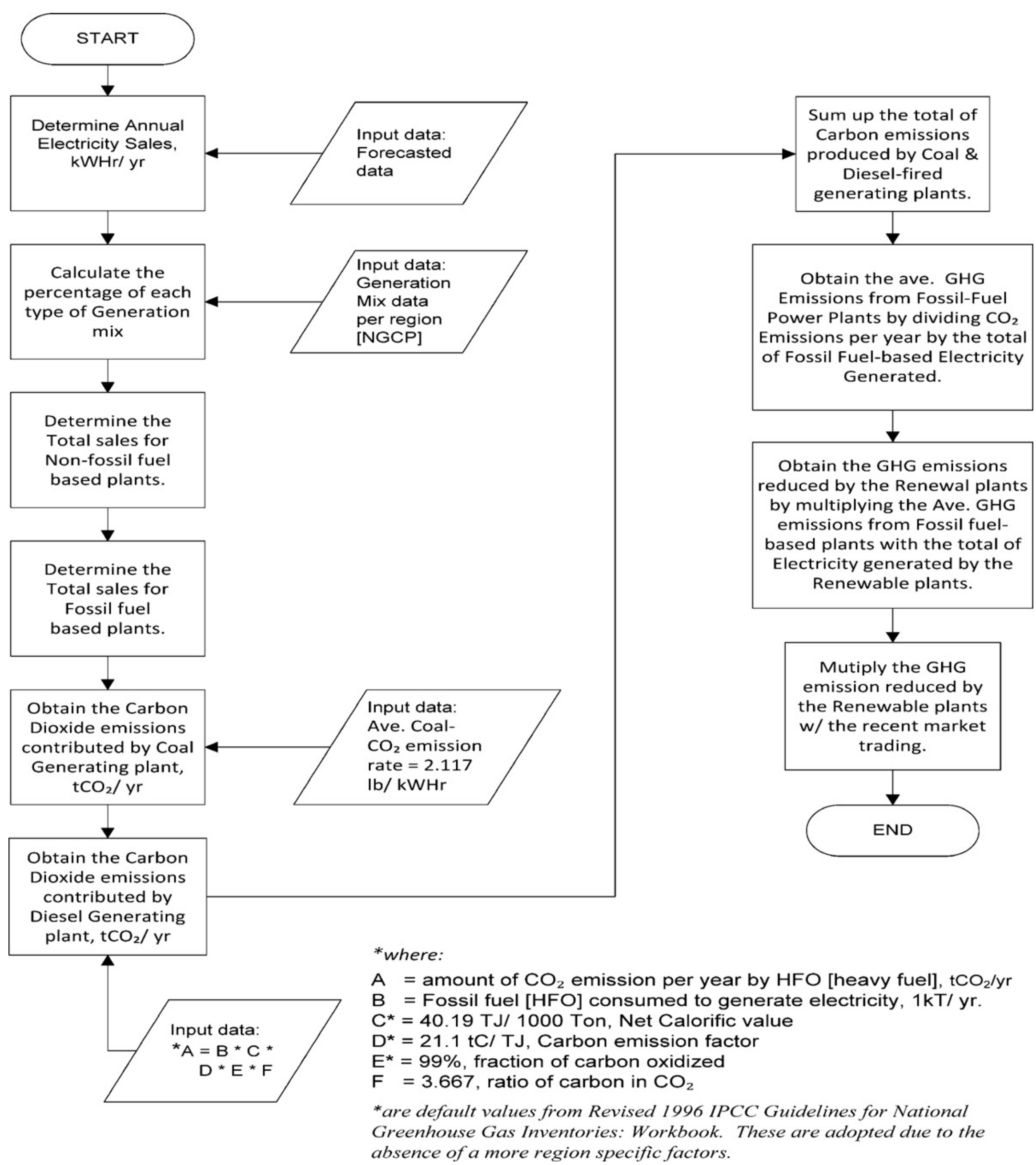


Fig. 6. Algorithm for determining CO_2 emissions of fossil fuel based generating plants.

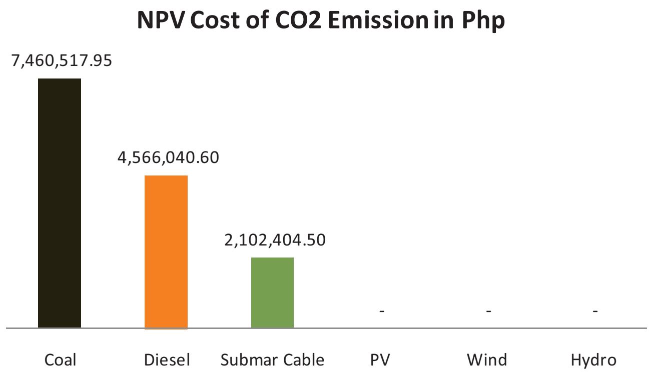


Fig. 8. Comparison of the NPV cost of CO_2 emissions per plant.

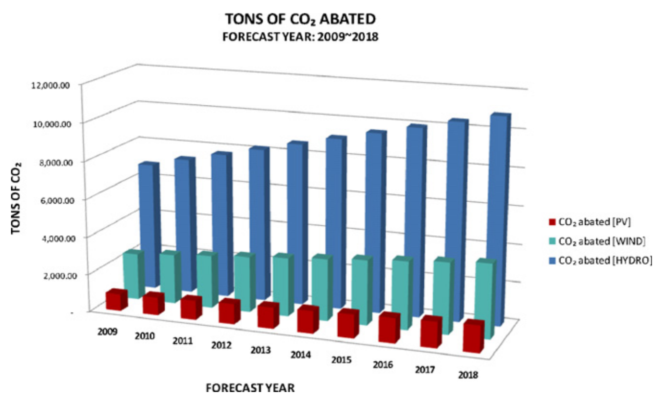


Fig. 9. CO_2 abated (2009–2018).

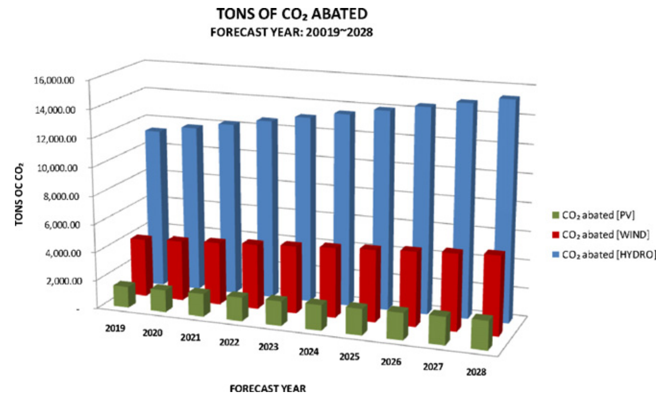


Fig. 10. CO_2 abated (2019–2028).

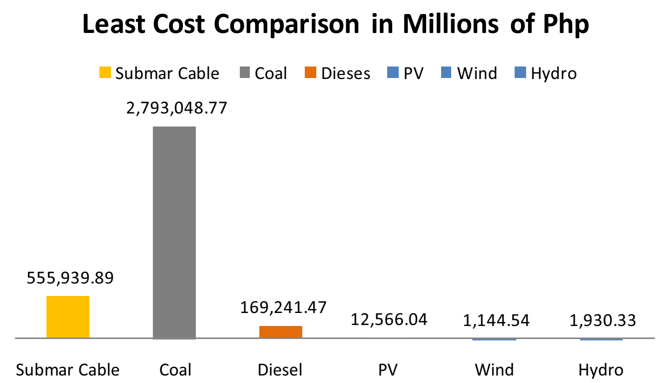


Fig. 11. Least cost comparison of the different generation schemes.

results of the analysis considering the CO_2 emissions for each of the generating plants.

2.3. *The significance of mitigating carbon dioxide emissions*

2.3.1. *Environmental significance*

When there is more carbon dioxide in the atmosphere the temperature gets warmer thereby producing the green house effect. Carbon dioxide having never gone above 300 parts per million prior to year 2000, has reached the mark of 500 parts per million in 2006 and will double the figures 50 years from now from a projected concentration. The matter of climate change and the effects of global warming has become a moral issue. Allowing the effects of global warming and the toleration of unrestricted fossil fuel burning is deeply unethical and leaves the future generations fried in a microwave phenomenon if left unabated.

2.3.2. *Economical significance*

Power generating plants contributes 60% of the total carbon dioxide emissions into the atmosphere. From the calculated data above, the operation of renewable plants such as PV, wind and hydro offsets a substantial amount of CO_2 concentrations emitted into the atmosphere as compared to operating fossil-fuel based plants such as coal and diesel. In the 20 year study, setting aside geographical viability, it is even much more economical to operate renewable plants such as PV against coal.

Through time, fossil fuels will be depleted and we may be able to develop new ways in generating energy. But the consequence of man's ever increasing demands for energy sources to sustain life-leads us to producing pollutants that kills the atmosphere that protects life (Table 1).

3. Highlights of findings and discussion/data presentation

The load demand forecast shows a 36% increase for the next 20 years or an average annual increase of 1.8%. This indicates a positive growth in the use of electricity in the utility. Although load demand and sales data are directly related, experience show that

Table 1
Least cost comparison.

Economic comparison						
	Subcable	Coal	Diesel	PV	Wind	Hydro
Initial/installed cost	200,000,000.00	450,000,000.00	78,000,000.00	11,250,000,000	956,250,000	472,500,000
NPV of O and M	2297287.26	1,033,779,265	134,391,304.5	1,292,224,082	164,758,570.4	162,820,234.3
NPV of fuel cost	555,734,223.524.92	2,791,561,508,349.23	168,916,912,923.77			
NPV of periodic maint	3,320,538.21	3,320,538.21	112,068,164.74	23,814,485.01	23,534,314.60	1,295,009,903.70
NPV of CO_2 Em.	46720.09	165,789.29	101,467.57			
Least cost:	555,939,888,070.49	2,793,048,773,941.96	169,241,473,860.56	12,566,038,566.54	1,144,542,884.99	1,930,330,137.97

Table 2
Annual peak power demand in MW/year. Historical data 2001–2009, forecasted data 2010–2030.

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
3061.348	3178.564	3295.779	3412.995	3530.209	3647.427	3764.64	3881.857	3999.07	4116.287
2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
4233.502	4350.717	4467.933	4585.148	4702.364	4819.578	4936.794	5054.008	5171.224	5288.438
2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
5405.654	5522.868	5640.084	5757.299	5874.515	5991.729	6108.947	6226.16	6343.377	6460.59

there are a lot of factors, like none-technical loss, that give rise to its difference. Load demand forecasts are necessary base for design computation while sales forecast are significant for economic evaluations.

Technical loss depends upon the physical condition of the system, like its line parameters and circuit topography, and the location of the distributed generation system. In this study computer simulations of the distribution system were used to determine the technical loss of the system. Results shows that wind and hydro based DG units may incur large losses due to their geographical limitations, while the more flexible ones, like coal and diesel, with respect to locations, can minimize losses.

The carbon emissions considered in this study is limited only to carbon emissions incurred due to plant operations. This means that carbon dioxide emitted due to the manufacturing of its parts are excluded.

A comparison of their carbon dioxide emissions shows that coal and diesel plants have large CO_2 emissions. Not only its effect in the environment is enormous but also the economic cost of cleaning them is also, if considered according to the carbon trading rate are also large. Carbon emissions in the coal and diesel plants come from its fuel.

In the economic comparison, fuel costs are the largest costs that these plants will incur in the long run. Least cost comparison of the different plant options shows that coal has the highest cost and diesel is the next. This means that in the long run coal and diesel plants would be more expensive to operate as shown in Fig. 11 [3,7].

Renewable energy power plants, like wind farm, hydro and photo-voltaic, have higher initial costs but very low operational and maintenance costs, having no consumable fuel to run its operation. Furthermore, they do not emit CO_2 into the atmosphere. This is shown in Table 4. So, instead of paying for carbon emission, renewable DG units, reduce or abate carbon emission and earns carbon credits.

4. Conclusion and recommendation

The technical, environmental and economic evaluation shows that, for the particular utility under consideration, renewable distributed generation units could greatly mitigate CO_2 emissions and are less costly to operate in the long run than fossil fuel based plants.

Appendix A.

Tables 2 and 3.

Table 3
Annual energy sales.

Year	kW h sales
2009	13148819
2010	12875647
2011	13661761
2012	14447875
2013	15233990
2014	16020104
2015	16806218
2016	17592332
2017	18378828
2018	19165291
2019	19951755
2020	20738218
2021	20738218
2022	21524681
2023	22311144
2024	23097608
2025	24670562
2026	25457054
2027	26243546
2028	27030037
2029	30305414
2030	31163407
Total	450562509

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Further reading

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